Electron-Atom Collision Studies Using Optically State Selected Beams

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We have undertaken a broad experimental research program in which we will study in a general way the role of electron spin in electron - atom interactions. Of primary interest is the effect of the exchange interaction in low energy elastic, inelastic, and ionizing collisions between electrons and alkali atoms. Also to be investigated, however, is the effect of the spin-orbit interaction in low energy collisions.

The experimental method we have chosen is crossed-beams scattering with optical state selection of the incident beams. The use of state selection permits one to extract information about the scattering process which is inaccessible to conventional scattering measurements. For all experiments in the early stages of this work, the use of state selected incident beams allows us to determine not only the differential scattering cross sections, but also to observe directly the ratio of the cross sections for scattering when the incident electronic and atomic spins form a triplet versus a singlet state. Future measurements are planned which add state interrogation of the scattered particles, enabling us to determine also the relative phase between the triplet and singlet scattering amplitudes. For favorable circumstances, this would constitute a complete measurement of the quantum mechanically allowed observables.

Polarized electrons are produced by photoemitting electrons from a negative electron affinity GaAs photocathode using circularly polarized light. Beam energies vary from 2 to 40 eV with currents that are space charge limited at the lower energies and may be as high as several microamps at the higher energies. The width of the energy distribution is typically 0.10 to 0.15 eV. We have shown during the past year that with proper treatment of the photocathode the energy width can be narrowed to 0.03 eV with no degradation of the spin polarization, achieving at the same time one order of magnitude increase in current over conventional monochromatic sources.

The atomic beam is collimated from an effusive oven and polarized by laser optical pumping. There are three strong advantages of this method for polarizing the atoms. First, the direction of polarization is conveniently and reliably reversed by reversing the helicity of circularly polarized light. Second, because the incident laser direction provides a quantization axis, no guiding magnetic fields are required. Third, with modest power levels in the optical pumping region, up to 30% of the incident atoms can be maintained in the first excited state, allowing scattering experiments to be performed on the excited atoms.

In the past year we have completed the determination of the spin asymmetry near the threshold for electron impact ionization of atomic sodium. There has recently been extensive discussion[1] of the relative merits of the Wannier[2] and Coulomb-dipole[3] theories of electron-impact ionization of atoms. It has been suggested[4] that a study of the spin dependence of the near threshold ionization process might reveal an oscillatory structure characteristic of the Coulomb-dipole theory. The Wannier theory, as extended to include spin,[5] predicts a spin dependence which does not vary with energy near threshold. We have therefore carried out a measurement of the energy variation of the spin dependence for near-threshold ionization of sodium with high precision and with higher electron energy resolution than previous experiments.[6] Our measurements are in agreement with the Wannier theory's prediction of a uniform, structureless asymmetry up to 2 eV above threshold. Further, we agree with the Wannier power law prediction of the ionization cross section up to about 0.8 eV above threshold with a measured energy exponent of 1.097±0.17. We see no evidence of the structure characteristic of the Coulomb-dipole theory. We conclude that if oscillations characteristic of the Coulomb-dipole theory exist, they must lie outside the range of our current experimental parameters. That is they are confined to a region closer to threshold, or vary so rapidly as to not be observable with electron beams of 0.09 eV energy width.

Future experiments require complete information about the electronic and atomic spin polarizations. Uncertainties in these quantities do not affect the relative error between measurements at different energies, but are reflected in an uncertainty in the overall magnitude of the observed spin asymmetries. In order to reduce this error in the overall magnitude of the asymmetry for future experiments, we have undertaken a careful diagnosis of the laser optical pumping process by observing the polarization of resonance fluorescence from the optically pumped atoms. Experiments from other research groups[7] had indicated that the simple rate equation model for optical pumping might be insufficient to completely describe the process and that the degree of atomic polarization achievable might be substantially less than the 63% predicted from the rate equations. Our measurements indicate that, at least for our experimental conditions, the rate equations do accurately model the optical pumping and that the atomic polarization is near its optimum value, or about 60±3%. These measurements revealed that certain experimental parameters, most notably the laser frequency, the degree of circular polarization of the laser light, and the local residual magnetic field, affect the optical pumping in a sensitive way. This suggests that the previously mentioned discrepancies between the model and experimental results could be ascribed to experimental effects not properly included in the rate equation model.

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